"SLIDES" IN THE CONEMAUGH FORMATION NEAR MORGANTOWN, WEST VIRGINIA

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FOREWORD

The purpose of this paper is a systematic discussion of "slides" in and near Morgantown, West Virginia. The abbreviation of the term "landslides" is in accordance with common usage in this locality, slides being a familiar term of everyday speech, so common is their occurrence. Either designation is somewhat of a misnomer as movements are not limited to true sliding.

As this article has a somewhat local bearing the general literature of the subject will not be quoted, though it is but just to state that the writer has received from this source some hints which have helped him in interpretations and comparisons. He

must, however, express his indebtedness to the reports of the West Virginia Geological Survey; also to Professor S. B. Brown, his colleague and chief, who has spent much time in acquainting him with the area. He is especially obligated to Dr. I. C. White, state geologist, and to Mr. David B. Reger, assistant state geologist, for their thoroughgoing review of the paper and constructive criticisms which have been freely used in its revision.

The slides studied occur in the Conemaugh Formation of the Pennsylvanian epoch. This is a series of alternating beds with shales predominating, in this locality approximately horizontal. The total thickness outcropping averages about six hundred feet. All shale members when exposed a short time to weathering agencies break down, if sufficient water is present, into a slippery, claylike mud. This creeps, slides, or even flows until the angle of repose is attained.

Slides, in the aggregate, constitute one of the big factors in the base-leveling of the area. Where numerous they produce a typical topography with features resembling those produced by glaciation and drainage. Less prominent forms frequently associated with slides are the "hoodoos" and ice pinnacles.

The Conemaugh is in a measure representative of several later formations of the Carboniferous, which show closely corresponding topography over much of the northern part of the state where such shaly sediments prevail.

While a single slide is rarely responsible for any great damage, in the aggregate slides become very effective. The total direct and indirect loss amounts to a heavy toll yearly. Some of the damage may be prevented by proper precautions, but the problem is too big for the adoption of absolute preventive measures.

GEOGRAPHY

The area studied with reference to slides is in Monongalia County, West Virginia, about five miles south of the Pennsylvania boundary. Morgantown may be considered the center. Through the area winds the Monongahela River. The Indians recognized the unstable character of the lands adjacent to the Monongahela by this name, which translated means "River of the Caving Banks."

The region is one of mature topography, with a relief averaging about five hundred feet.

GEOLOGY

The geologic maps of the State Survey show exposures in Monongalia County of Carboniferous formations succeeding toward the northwest in approximately parallel belts. The Monongahela River is here practically confined to a course in the Conemaugh, with its valley walls usually showing exposures of most and sometimes all of this formation.

The members of the Conemaugh are approximately horizontal at Morgantown. Elsewhere the dip is prevailingly toward the northwest with interruptions by mild anticlines and synclines. While a decided dip would undoubtedly have some influence on slides, it is believed for the purposes of this paper that the exposed areas of this formation may be considered as horizontal.

The Conemaugh is composed of alternating beds of shales, sandstones, coals, and limestones, with a total thickness varying from five hundred to six hundred feet. Shale and sandstone members vary from a few feet to over fifty feet in thickness. About four feet is the usual maximum for coal or limestone members.

SLIDES

ORIGIN AND EXTENT

Three factors may be considered necessary for the slides discussed. There must be a material which will take the proper consistency, slope, and water. Any of the Conemaugh shales may furnish the material. The degree of slope necessary is practically indeterminable, this varying with water content, thickness, and stratigraphic position of the shale. In extreme cases movements of the more fluid type will take place on nearly horizontal surfaces.

The shales generally are quite fissile, jointed, and slickensided, and tend to become saturated with water, the downward movement of which is successively impeded by the less pervious beds. This water evidently has little effect on the stability of the shales where they are not exposed to the air and excessive temperature changes. Cuts exposing unweathered shales show that these will

hold nearly vertical positions until effectively weathered, which may take from one to several seasons. Under the combined influence of the oxidizing action of the air, water, and temperature changes, especially freezing when water laden, the shales are shattered and comminuted until a slippery claylike mass is produced. Deep freezing is temporarily effective in stopping slide movements, though the result when thawing is a hastening of the process, as the mass more readily breaks away after the aid given by the expansional and contractional movements of freezing and thawing.

The transverse strength of a weathered shale mass is much less than that of the parent body, and when such a mass is sufficiently weighted with water it tends to break away from the latter and so originates the slide. With the breaking away a comparatively fresh surface of the shale is again exposed, so that the process is free to continue indefinitely at the same point or at least until an equilibrium between gravity and tenacity of materials is attained.

Weathered shale on drying becomes hard, and shows no tendency toward movement except in loose surface material.

TYPES AND DYNAMICS

Slides in the Conemaugh may somewhat arbitrarily be divided into three classes, (1) primary, (2) fluid, and (3) dry. These shade into each other or may combine.

1. *Primary.*—These are slides in which the moving mass is highly saturated with water and of the consistency of a thick mud. The primary slide is the first to form and decidedly the most important in totality of effects. The movements are rarely observed though it is believed movements fast enough to be visible are of not infrequent occurrence. Results may often be noted daily in active slides. A new movement of this sort is heralded by a break in the sod, the break tending, with occasionally marked variations, to follow a contour line. The position of this break is further affected by the relative toughness of the sod. Paths, since sod is weak or lacking, offer lines encouraging breaks. A single break is rarely of great linear extent, but the whole face of a hillside may be at times seamed with them. These breaks really

mark a variety of fault plane, the heavily weighted and weakened masses, impelled by gravity, breaking away and slowly dropping and sliding from the parent body. The movement tends to churn the mass rendering it more fluid so that later motion, still unobservable, has apparently an element of flowage. As the slide progresses, the face left bare by its movement widens, sometimes to many feet. This face has usually a much steeper gradient than the mass which previously covered it, offering a ready point of attack by the elements and gravity, so that by repetitions of the sliding process, one starting at the base may be responsible for a successive series to the top of a hillside.

As these slides are closely associated with the ground water, new breaks often show this exuding from their surfaces, their originally somewhat fissile faces soon slaking to a mud-plastered effect. The ground water may be sufficiently abundant to form a stream previously non-existent, which in turn may channel a gully that will determine the drainage flow of the immediate area.

In the same way that slides originate in the fresh shales, later slides repeatedly affect the masses of earlier slides, the process being active only when the material has ample water content.

As an explanation of the common terrace form resulting from slides, the following is suggested: Movement of the slide mass favors its drainage, and when sufficiently drained movement ceases. As drainage is most effective at the front, forward movement lags or ceases at that point first. By pressure of the still undrained rearward mass, the front in its resistance may be forced upward. The result is a hummock with a bare and steeply sloping front, a top of gentle slope which may be even roughly level or dip back toward the hillside, giving favorable conditions for ponding of water and further slide movements; at the rear, the bare steep slope marking the upper border of the surface from which the slide has broken away.

Whether by weakening of their support due to slides on the downslope side, or a crowding due to a faster movement on the upslope side, trees under their influence usually tend to incline downhill. As the roots are anchored in unstable earth, the unbalanced condition of the tree further accentuates this tendency.

When the forward frontal movement ceases or slows the upward crowding of this part may restore any trees upon it to a normal position or even to one inclining uphill. Occasionally trees may be seen inclining uphill on rather steep slopes. The slides producing this result are possibly of greater extent, with less differential and more rapid motion, and a counteracting tendency due to the inertia of the tree, most effective in its upper portion. Leaning trees are not as numerous as one might expect. This is largely due to the fact that they hinder slide movement. Thickly wooded hillsides rarely show such movement.

The vegetation on a slide frequently continues growing as though undisturbed. Between successive seasons of movement the breakage surfaces may become sod covered. Hillsides showing an almost kaleidoscopic change of surface may nevertheless be covered most of the time with a mat of vegetation.

Other things being equal, the thicker a shale the more subject it is to slides, although a thin shale underlain by particularly impervious material may be as troublesome as a thicker layer less favorably situated.

The intervening layers of other rock between shale beds frequently furnish a hindrance to the progression of slide movements uphill, as well as serving to initiate independent slide movements. Such layers, undermined by slides, will in time break off in blocks of size determined mostly by the joint and bedding planes.

2. *Fluid.*—This, the second type of slide, may be considered as an extreme stage of the first. In this type the proportion of water is so great and so thoroughly mingled with the shale mass, that the whole goes downhill in usually visible motion, like a thick fluid. On reaching a surface of sufficiently gentle slope, the heavier materials spread out and settle, leaving the water to drain away from the edge and over the surface like distributaries. These slides, like the third type, are not of great significance.

3. *Dry.*—The dry, or third type of slides, are those with a true sliding or rolling movement downward. On slopes barren of vegetation, movements in the material and drying may so loosen the surface covering, especially of shale flakes, that portions of this will move down in the manner stated unless checked by obstacles

or a lessened slope. If the obstacles are not sufficiently resistant, they may be loosened and may also move forward. Slides of the dry type are frequently observable as an aftermath to the slide movements of the first or second types, which are usually responsible for the barren surfaces upon which the third type originate. Generally the sliding mass is very small in bulk so that this type is probably the least effective in total results. Inasmuch as all the slides in these shales are primarily caused by water saturation, these dry slides are merely secondary effects, tending to re-establish the disturbed angle of repose.

TOPOGRAPHIC FORMS PRODUCED BY SLIDES

Several topographic forms have already been suggested, but it was thought desirable to classify together those which simulate the forms produced by other agencies.

RESEMBLANCE TO GLACIAL FORMS

The irregular surfaces produced by differential motion, especially when the forward part of a slide or combination of slides is crowded up, may give a gently pitted topography favoring the accumulation of water in the depressions. The lakelets thus formed are rarely permanent but may persist throughout the winter. These isolated surfaces suggest modest morainic topography. Sometimes whole hillsides are so cluttered with hummocks of slide masses that they resemble mild kame and kettle areas upon a tilted base. The scattered rock masses on hillsides, while usually more angular, bring to mind the erratics of glaciated country. A hillside from which much slide material has removed takes on a re-entrant character similar to that produced by the plucking action of ice and snow in a glacial cirque. Indeed as suggested by my colleague, Professor Brown, the separation of the slide from the parent mass resembles the bergschrund of a glacier. As bowlders from the resistant formations are frequently mingled in haphazard fashion with the clayey base, the heterogeneous character of glacial till is produced.

RESEMBLANCE TO DRAINAGE FORMS

Upcrowded masses, when of considerable extent, frequently resemble river terraces. These semblances may be hundreds of

feet in length, but rarely more than thirty feet in width. (Successive breaks in a slide mass often result in a series of small terraces or steps which may be likened to step faults.) In some cases the terraces are due to the position of a resistant rock ledge (Figs. 1 and 2). The overlying shales on this having been removed previously

FIG. 1.—Terrace at base of left-hand re-entrant as shown in next view. Slide material has accumulated irregularly on a ledge of the Saltsburg sandstone (in Lower Conemaugh), resulting in a general terrace form with lakelets of precarious life in the hollows.

either by slides or former river action, subsequent slides have spread over the top and flattened to rough conformation with the rock ledge.

Sometimes slide material will accumulate at the base of a slope in the form of a fan or cone, the accumulation probably being the result of a combination of the slide types. A hillside cut marking the source of at least some of the slide material usually leads to it. While these features are still fresh their origin can hardly be questioned. With the passage of time the slide gullies may become

true drainage lines, and the fans and cones become covered with vegetation. They would then be mistaken for forms of stream origin. There is little doubt that many of the so-called alluvial fans and cones in the area discussed have had this history. The later modification may entitle them to their present names. The delta-like products of the fluid slides would also originate such forms.

FIG. 2.—Two huge re-entrants meeting. These are the product of slides which have progressed to near the hilltop. Note the steepening effect produced by slides at their upper limit. The ultimate result, obviously, will be a reduction in the height and gradient of the hill. Slides are still active over the entire surface of the re-entrants; several terrace-like forms are discernible in their midst. The terrace marking the base of the re-entrants, though covered with irregularly placed slide material, has had its form determined by the Saltsburg sandstone which outcrops beneath.

MINOR TOPOGRAPHIC FORMS ASSOCIATED WITH SLIDES

"Hoodoos"[1] and ice pinnacles are frequently found associated with slide materials.

HOODOOS

These are usually abundant on slide slopes after heavy rains. Great numbers will sometimes stand out as distinct columns, but on the steeper slopes the columns with their caps frequently coalesce

[1] See article by Rolf A. Schroeder, *Journal of Geology*, Vol. XXVII, No. 6, pp. 480–81.

on one side with the slope. This form may be so numerous as to give the whole surface of such a slope a peculiar columnar structure. Both kinds of hoodoos are evanescent features.

ICE PINNACLES

These forms are apt to coincide with the melting of snows on steeply sloping fresh slide surfaces, though it does not appear that slope is always necessary. They are tapering columns of ice a few inches in length, coalesced toward their bases, the columns extending with considerable variation at right angles to the surface on which they rest. While the individual pinnacles tend to be straight, many are curved and hooked in curious fashions. They are of principal interest in connection with this paper in that they as well as other ice masses permit the ready transmission of light to the frozen ground beneath where it is absorbed as heat, resulting in a superficial thawing of the surface and a melting of the underside of the ice. No longer properly secured these ice masses, with any enmeshed mud, break off and slide down. This also encourages movement in the thawing muds beneath.

TOTALITY OF EFFECTS

GENERAL TOPOGRAPHIC EFFECT

Taken in the large the topography is little different from a typical area in maturity, though broad hillsides sometimes show huge re-entrants or hummocky surfaces with frequent small terraces. Outcrops of resistant rock frequently indicate their position by steeper slopes even when slide covered.

A number of relatively large discontinuous terraces mark old positions of the Monongahela and tributary streams. These stream terraces may have some association with slide movements. In fresh cuts evidences of stratification, while not infrequent, are less common than till-like coverings. It is tentatively suggested that since the lowering of the streams, movements within the terrace deposits and the addition of slides from the hills may account for the heterogeneous masses so often found.

Where old valleys of somewhat shallow depth are practically confined to shales, the slopes are more mature, as the sliding

continues unchecked by beds of resistant rock. As limestone and coal members are generally weak, the interfering rock is practically limited to the thick sandstone beds.

IMPORTANCE AS A BASE-LEVELING FACTOR

The importance of these slides as a base-leveling factor can hardly be overestimated. Widespread changes are observable as a result of a single season of activity. No other single agency produces comparable results except as associated with this factor. In this sense streams are of highest importance as by their removal of slide masses, a continuency of the movements is permitted.

INFLUENCE ON DRAINAGE

Gully-like forms and similar depressions due to slides are such common features of hillsides or at the edge of slide or stream terraces, that they furnish the readiest lines for drainage of nearby surface areas and for the ground water. It is very probable that most of the minor streams whose courses have been determined under present stratigraphic conditions have had these courses determined in some measure by such depressions.

SIMILARITY OF THE CONEMAUGH TO OTHER FORMATIONS

The Monongahela and Dunkard formations which were laid down following the Conemaugh, show a somewhat similar stratigraphic arrangement with shales of unstable character. Their outcrops, like the Conemaugh, lie in the Alleghany Plateau. Gently dipping northwest, with usually mature topography, slide conditions throughout their outcropping extent do not differ greatly from those of the Conemaugh, though the Dunkard shows some interesting differences.

ECONOMIC CONSIDERATIONS

While most of this territory is subject to surface modifications on account of slides, the damage within the city of Morgantown is less serious than might be inferred. This is due in large measure to the situation of most of the city on the several comparatively level terraces of the Monongahela River and tributaries. By utilizing the connecting slopes as well as some of the land rising

above the well-defined terraces, the city has avoided extending its territory excessively. The connecting slopes have caused little trouble in the business district. This is in part due to the fact that the terrace positions were largely determined by the resistant rock. The removal of slaked shales, grading, and the protective effect of building and paving operations have all helped in preventing serious trouble. In the outlying territory dwellings built on

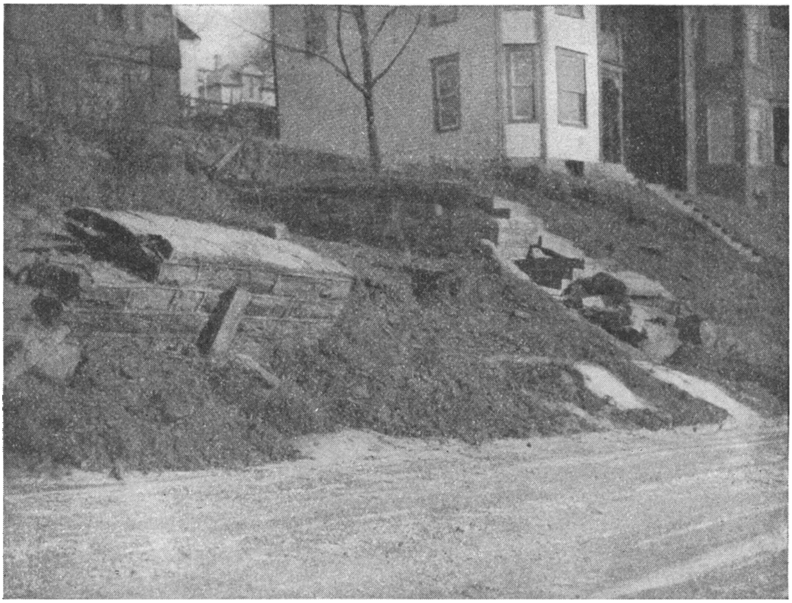

FIG. 3.—Walls and steps pushed forward as a result of slide movements. The house in the foreground is in immediate danger. Note jagged edge of broken brick walk leading to house in the rear. As is frequently the case, the sliding masses have produced a terrace-like form, with the vegetation growing on its top but little disturbed. Many months were required to produce the foregoing result.

terrace slopes and on the upper hill slopes are sometimes endangered by slides, and precautions have to be taken to prevent their destruction. The most effective preventive of trouble is the exercise of foresight, the position a house is to occupy being considered with reference to this difficulty. Sometimes thick retaining walls are built at the time to insure safety. That such walls prove inefficient at times is shown by the accompanying figure. Some

lots plotted for building purposes are totally unfit for such use, a fact which usually becomes apparent before construction is started. In a few instances the grading of roads, or changes of drainage by fillings or other causes, has been charged with starting slides endangering structures. Such instances have usually resulted in lawsuits to determine the influence of such changes and also to place responsibility.

FIG. 4.—Slide partially blocking roadway. The entire face of the slope above the slide is bare to a height of about forty feet, the result of recent slides.

The greatest source of trouble comes from the roads leading out of the city. As the terraces on which the city is built are fragmentary, roads cannot follow them for great distances. If outlying districts are to have communication with the city, the building of roads along or at the base of hillsides is unavoidable. While poor engineering judgment is sometimes shown in locating the roads, with the best of skill the ultimate damage can only be lessened. The present roads, including several regraded and paved within the last few years, have suffered repeatedly, sometimes by block-

ing caused by upslope slides, sometimes by caving, the result of downslope slides. The most obvious remedy for the former is to reduce the slope by cutting away on the uphill side, and to produce the same result by filling in on the lower side. On the new slopes so made the growth of vegetation should be encouraged. It might prove practicable in extreme cases to prevent saturation of the trouble-making shale by well-planned drainage. Heavy retaining

FIG. 5.—Slides have undermined the brick-paved road at this point. The line of dirt through the center of the road fills a crack and reduces the gradient between the sides of the offset. At the far end marked by the position of the man, half the road has dropped to such an extent as to require blocking off.

walls should be successful in some instances. These remedies may be considered applicable only in extreme cases, or with such portions of the road where the trouble is due to the cut made in grading. The total avoidance of damage would mean a cost in preventive arrangements greater than the total of prospective damage.

Electric railroads are subject to the same conditions as the highways. The steam railroads in the immediate vicinity of

Morgantown are built on natural or artificial terraces cut in the Buffalo sandstone, one of the lower Conemaugh members. As the lower part of this massive sandstone forms the river bottom, the railroads here are free from undermining, but subject, especially when following close to the hillsides, to occasional slides from above. The removal of these causes immediate expense as well as delays. By the liberal use of watchmen in deep cuts and frequent "slow orders" in times of excessive rainfall, few wrecks are fortunately chargeable to this cause. A better understanding of the shales would result in relocating parts of the tracks.

As slides are much more frequent in seasons of abundant rainfall than in seasons of light fall, the damage to roads and various structures and loss by delays increases or decreases accordingly. The past year (1919) was one of abnormal rainfall, roughly about one-fourth greater than the average, the fall months having more than their share of the excess; consequently the year and especially the latter months proved unusually costly. The generally slow movement and small volume of the individual slides have meant that private parties have rarely suffered disastrous losses. While no total can be estimated for the average yearly loss to the community, there is no question that this would amount to a big sum.

An indirect loss, though much more than all others in the aggregate, is that caused by the withdrawal of farmland from cultivation. Slopes not too steep for the plow under light rainfall conditions, when charged with water may start movement which a vegetative covering would have checked. Such slopes are best reserved for grazing or forest growth. This is well understood by farmers, and very little land except flood-plains, terraces, and hilltops is ever plowed. The effect of the Conemaugh in limiting cultivation is well indicated by the fact that other and especially older formations in West Virginia permit cultivation on much steeper slopes than allowable in the Conemaugh, without sliding.

The shale soils, where they can be used, are generally productive. Especially is this true when they have a pronounced lime content, either native or infiltered from higher beds.

The frequent undermining of sidewalks along the roads on the edge of the city would seem to furnish a fruitful source for accident,

likewise the obstruction or falling in of roads. The frequency, however, is itself the safeguard, the population having become educated to the danger, and consequently taking proper caution. The injuries from such causes have been few.

It may be noted that slides have never been of sufficient extent to interfere with the use of the Monongahela River since rendered navigable.

The only direct economic benefit from the slides lies in the fact that brick, ordinarily made by grinding the shale, can be made of almost equally good quality and less expense for handling from the slide material. When work in the shale is interfered with by slides, the material in these is used.

The shales worked at present near Morgantown are near the base of the Conemaugh, though shales higher in the formation are frequently used elsewhere. Formerly brick was made from river-terrace clays, these clays resulting doubtless from the assortment of shale muds reaching the rivers as slides and from direct stream action.